VULNERABILITY AND LANDSCAPE ASSESSMENT IN INDIGIRKA RIVER BASIN, EASTERN SIBERIA, RUSSIA

M.S. Boori [1,2,4], K. Choudhary [1], A. Kupriyanov [1,3], A. Sugimoto [4], V. Kovelskiy [1]

[1] Samara State Aerospace University, Samara, Russia
[2] American Sentinel University, Colorado, USA
[3] Image Processing Systems Institute, Samara, Russia
[4] Hokkaido University, Sapporo, Japan Abstract

Monitoring of land use/cover change is very important for sustainable development and planning. This research work is to understand natural and environmental vulnerability situation and its cause such as intensity, distribution and socio-economic effect in the Indigirka River basin, Eastern Siberia, Russia based on remote sensing and Geographical Information System (GIS) techniques. A model was developed by following thematic layers: land use/cover, vegetation, wetland, geology, geomorphology and soil in ArcGIS 10.2 software using multi-spectral satellite data obtained from Landsat 7 and 8 for the years of 2000, 2008 and 2015 respectively. This study is helpful for decision making for eco-environmental recovering and rebuilding as well as predicting the future development.

Keywords: Land use/cover, Change detection, Natural and environmental vulnerability, Landsat data, Remote Sensing, GIS.

Introduction

Russia has a largely continental climate because of its sheer size and compact configuration. Most of its land is more than 400 kilometers (250 mi) from the sea and the center is 3,840 kilometers (2,386 mi) from the sea. Presently remote sensing and GIS techniques are the powerful tool to investigate, predict and forecast environmental change senior in a reliable, repetitive, non-invasive, rapid and cost effective way with considerable decision making strategies [1-3]. This research work uses a new approach by integrating the above mention potential impacts for vulnerability assessment. Analysis can help to solve the multidisciplinary problems such as most or least vulnerable regions, their comparing, in un-assessable and harsh climatic conditions. In this research work we use geology, geomorphology, soil, wetland, vegetation and land use scenarios for vulnerability assessment [4-5]. In this context, the main aim of this study is: (1) build a model of spatial distribution of natural and environmental vulnerability through remote sensing and GIS; (2) knowing the parameters used to obtain clarity of vulnerability; (3) knowing the level of vulnerability in different parts of the study area [6-7].

Study area, data and methodology

The study area is located in the Indigirka River basin, eastern Siberia. The geographic coordinates are in between 68°58'01" to 72°43'40" N latitude and 147°18'12" to 153°24'20" E longitude. In this research work we used primary (satellite data) and secondary data such as ground truth for land use/cover classes and topographic sheets. The ground truth data were collected using Global Positioning System (GPS) for the year of 2008 and 2015 in the month of June to August for image analysis and classification accuracy. The specific satellite images used were Landsat ETM+ (Enhanced Thematic Mapper plus) for 2000 and 2008, Landsat OLI (Operational Land Imager) for 2015, an image captured by a different type of sensors [8].

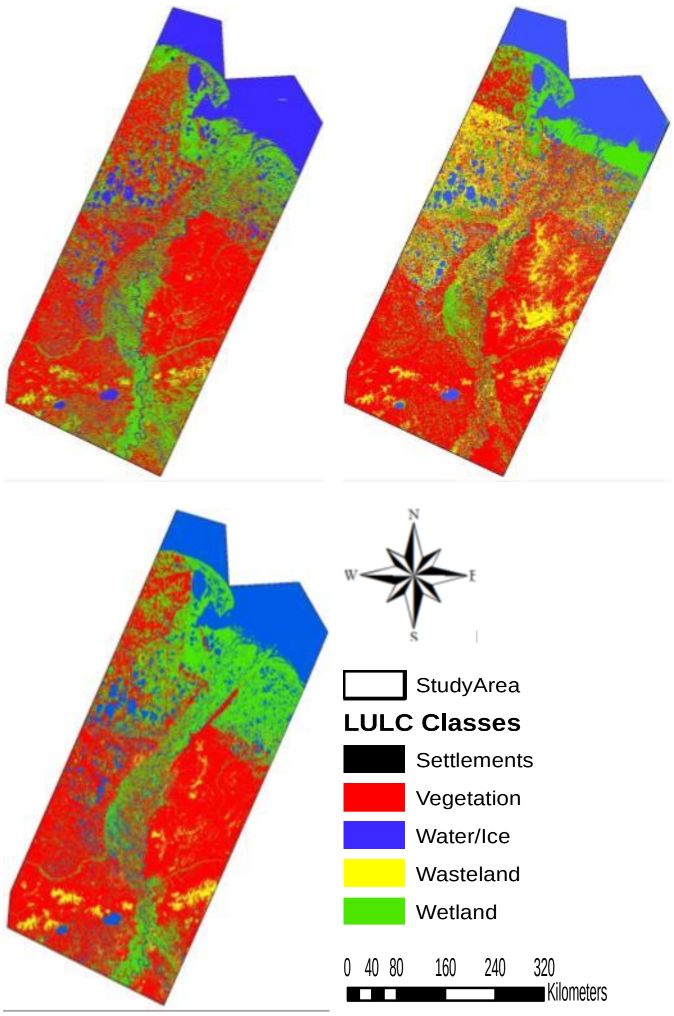


Fig. 1. Land use/cover status of the eastern Siberia; (a) in 2000, (b) in 2008 and (c) 2015 (based on Landsat ETM+ and OLI Satellite Imagery).

All multi-spectral and temporal data were georeferenced based on topographic sheets with the help of ArcGIS 10.2 software. To improve the quality of research analysis we used different band ratio, image enhancement techniques, and principal component analysis and in last supervised classification (fig 1).

Thematic maps of geology, geomorphology, soil, wetland, vegetation and land use/cover were prepared from Landsat ETM+ and OLI imageries. The weight of all landscape units was based on [9-10] stability concept. The weights of a landscape unit indicate the importance of any factor in relation to others [11-12]. In natural vulnerability all thematic layer give same weight but in environmental vulnerability all thematic layer were given different weight based on their sensitivity or effectiveness in the study area [13]. The degree of vulnerability for all units was range from 0.0 to 3.0 based on [7]. The degree of vulnerability varies from 0 to 3 and is ranked as extreme, high, moderate, sensible and low vulnerability. The weights of compensation indicate the importance of any factor in relation to others, as can be seen in the formula below for natural vulnerability and environmental vulnerability map.

For natural vulnerability:

[(Theme 1) + (Theme 2) + (Theme 3) + (Theme 4) + (Theme 5)] / 5

For environmental vulnerability:

0.2 X [Theme 1] + 0.1 X [Theme 2] + 0.1 X [Theme 3] + 0.1X [Theme 4] + 0.1X [Theme 5] + 0.5 X [Theme 6]

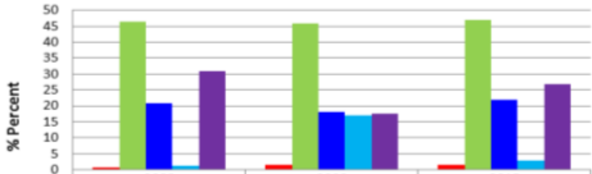
Where: Theme 1: Geomorphology map, Theme 2: Simplified geological map, Theme 3: Soil/soil system map, Theme 4: Vegetation/biodiversity map, Theme 5: Wetland map and Theme 6: Land use/cover map. The result mean was distributed in following five natural and environmental vulnerability classes: Low vulnerability: less than or equal to 1.00; Sensible vulnerability: 1.1 to 1.50; Moderate vulnerability: 1.51 to 2.00; High vulnerability: 2.1 to 2.50 and Extreme vulnerability: greater than or equal to 2.51.

Results

Land use/cover status

Figure 1 shows land use/cover image after supervised classification. These images provide pattern of land use/cover of the study area. The black color represent settlements, red color vegetation, blue color water/ice, yellow color shows the wasteland and green color shows wetland. All land cover class maps were compared with reference data, which was prepared by ground truth, sample points and google earth. Over all classification accuracy of the study area was more than 90% for all three dates.

Since last 15 years only wetland area has been decrease from 23011 km^2 in 2000 to 20059 km^2 in 2015 which accounts for 3.96% of the total study area (fig. 2). In the same time other class's such as settlements, vegetation, water/ice and wasteland were increase 0.85%, 0.54%, 0.95% and 1.62% respectively (fig. 2). From 2000 to 2008, the major change was in wasteland and wetland. Wasteland was increase 15.55% (11605km^2) and wetland was decrease 13.27% (9900km^2) of the total study area. From 2000 to 2008 total settlement area was increase from 453.59 to 1069.77km^2, which is 0.83% of the whole area. Water and vegetation area was reduced approximately 0.48% and 2.63% from 2000 to 2008 respectively (table 1). From 2008 to 2015 only wasteland was reduced around 13.94% (10398.41km^2) and other classes such as settlement, vegetation, water/ice, wetland were increased 0.02% (15.33km^2), 1.02% (761.15 km^2), 3.58% (2673 km^2) and 9.31% (6948 km^2) respectively (table 1).



	2000	2008	2015
Settlements	0.61	1.43	1.45
Vegetation	46.32	45.84	46.86
Water/Ice	20.87	18.24	21.82
Wasteland	1.36	16.92	2.98
Wetland	30.84	17.57	26.89

Fig. 2. Land use/cover for eastern Siberia in 2000, 2008 and 2015.

Table 1. Area and amount of change in different land use/cover categories in the study area during 2000 to 2015.

	2000		2008		2015		2000-2008		2008-2015		2000-2015	
Class	Area	%	Area	%	Area	%	Diff.	%	Diff.	%	Diff.	%
Settlements	453,59	0,61	1069,77	1,43	1085,10	1,45	616,18	0,83	15,33	0,02	631,51	0,85
Vegetation	34558,78	46,32	34198,86	45,84	34960,01	46,86	-395,92	-0,48	761,15	1,02	401,23	0,54
Water/Ice	15571,56	20,87	13610,66	18,24	16283,68	21,82	-1960,90	-2,63	2673,02	3,58	712,12	0,95
Wasteland	1015,66	1,36	12620,89	16,92	2222,48	2,98	11605,23	15,55	-10398,41	-13,94	1206,82	1,62
Wetland	23011,36	30,84	13110,77	17,57	20059,68	26,89	-9900,59	-13,27	6948,91	9,31	-2951,68	-3,96
Total	74610,95		74610,95		74610,95							

From 2000 to 2008 the main land encroachment was 9933.96 km2 area was converted from wetland to vegetation (table 2). In the same time period 0.05% (39.34 km2) settlement, 32.18% (24011.30 km2) vegetation, 17.34% (12938.81 km2) water/ice, 0.99% (740.83 km2) wasteland and 11.46% (8552.28 km2) wetland area was unchanged. Approximately 10.11% (7541.11 km2) wasteland was convert into vegetation from 2008 to 2015 (table 5). In this time period from 2008 to 2015, other classes as settlements 0.03% (21.31 km2), vegetation 34.18% (25947.25 km2), water/ice 17.53% (13077.70 km2), wasteland 1.42% (1060.34) and wetland 11.29% (8426.08 km2) was unchanged (table 5).

Table 2. Land use/cover change matrix showing land encroachment of the study area.

2000-2008	SETTLEMENT	VEGETATION	WATER_ICE	WESTLAND	WETLAND	Total
Settlements	39.34	32.78	75.39	22.95	299.94	470.39
Vegetation	345.83	24011.30	24.58	8753.88	1575.08	34710.66
Water/Ice	9.83	26.22	12938.81	11.47	2591.24	15577.58
Wasteland	18.03	127.84	44.25	740.83	157.34	1088.29
Wetland	655.60	9933.96	503.17	3119.01	8552.28	22764.02
Total	1068.63	34132.10	13586.21	12648.13	13175.88	74610.95

2008-2015	SETTLEMENT	VEGETATION	WATER_ICE	WESTLAND	WETLAND	Total
Settlements	21.31	381.89	8.20	21.31	635.94	1068.64
Vegetation	27.86	25947.25	6.56	1106.34	7062.52	34150.53
Water/Ice	1.64	45.89	13077.70	1.64	427.78	13554.66
Wasteland	514.75	7541.11	43.94	1060.34	3505.85	12666.00
Wetland	526.22	1014.55	3123.96	80.31	8426.08	13171.13
Total	1091.78	34930.70	16260.36	2269.94	20058.17	74610.95

Vulnerability analysis

Natural vulnerability map show that maximum area in safe zone as 38.61% area in sensible vulnerability and 29.84% area in moderate vulnerability zone, which represent that around 60% area of the total study area is safe zone. Around 14.54% area goes in high vulnerability which is really need proper management otherwise it will increase and will unsafe. The low vulnerability area is only 16.68% of the total study area, which is present in sea, river and water body area. Only 0.33% area has been under extreme vulnerability, which is very less and close to water bodies. High vulnerability area is close to costal line and near to river basin and in wetlands. High vulnerability is due to instability and extreme climate conditions. Maximum vegetation area and close to river basin area under moderate vulnerability zone. All wasteland area and some parts of wetland and vegetation are under sensible and low vulnerability area, which represent maximum safe area in the study area. It`s low vulnerability area due to less socioeconomic activities and high density of vegetation (fig. 3).

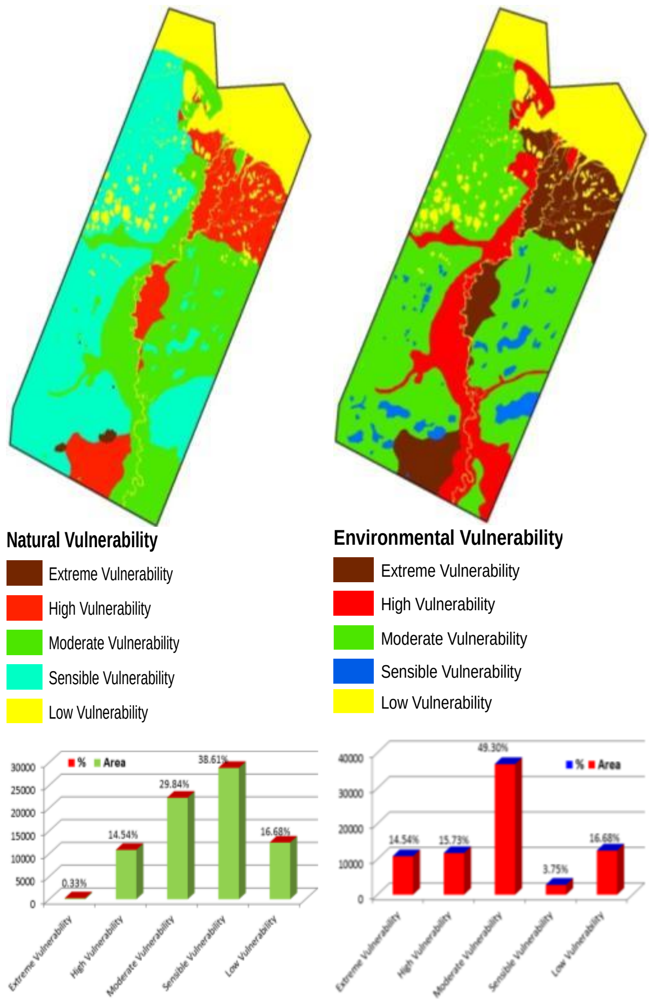


Fig. 3. Natural and environmental vulnerability map.

Environmental vulnerability map is more sensitive than natural vulnerability. In environmental vulnerability around 50% area under moderate vulnerability zone but high and extreme vulnerability is higher than natural vulnerability. Here 15.73% area under high vulnerability and 14.54% under extreme vulnerability. Sensible vulnerability is only 3.75% and low vulnerability is 16.68%. Low vulnerability is present in sea, river and water bodies and sensible vulnerability present in wasteland and some patches in vegetation. Maximum study area has been under moderate vulnerability, which is present in vegetation and close to wetland and costal line. High vulnerability is present in close to coastline and along to river and its channels. In the study area there is extreme vulnerability having three big patches in wetland, close to costal line and river (fig. 3).

Conclusion

After analysis find following conclusions:

- From 2000-2008 wasteland area was increased from 1015 to 12620 km2 by 15% and wetland reduced by 13%.
- From 2008 to 2015 wasteland area was shrink more than 13% and wetland augmented around 9% but in the same time period other classes have minor variation.
- Natural and environmental vulnerability can be modelled by using remote sensing and GIS.

- There is very less extreme natural vulnerability.
- Maximum area has been under moderate vulnerability zone for both type of vulnerability.
- Natural and environmental vulnerability is influenced by harsh climate conditions, vegetation cover, erosion, degradation of land and socio-economic activities.

Acknowledgements

This data work is financially supported by the Russian Scientific Foundation (RSF), grant no. 14-31-00014 “Establishment of a Laboratory of Advanced Technology for Earth Remote Sensing”.

References

1. Kok M., Lüdeke M., Lucas P., Sterzel T., Walther C., Janssen P., Sietz D., Soysa I.D. A new method for analysing socio-ecological patterns of vulnerability. Regional Environmental Change. 2016; Vol. 16 (1), 229-243.
2. Boori M.S., Choudhary K., Kupriyanov A., Kovelskiy V.. Four decades urban growth and land use change in Samara Russia through remote sensing and GIS techniques. SPIE Remote Sensing and Image Formation. 2015; 9817, 01-07. Doi:10.1117/12.2227992
3. Tricart E. Revista Brasileira de Geomorfologia Ano 8, nº 2 (2007), 1977
4. Chen, L., Michishita, R., Xu, B. Abrupt spatiotemporal land and water changes and their potential drivers in Poyang Lake, 2000–2012. ISPRS Journal of Photogrammetry and Remote Sensing. 2014; Vol 98, Pages 85–93.
5. Boori M.S., Choudhary K., Kupriyanov A., Kovelskiy V. Urbanization data of Samara City, Russia. Data in Brief. 6(2016), 885-889. Doi:10.1016/j.dib.2016.01.056
6. Aretano R., Semeraro T., Petrosillo I., De Marco A.D., Pasimeni M.R., Zurlini G. Mapping ecological vulnerability to fire for effective conservation management of natural protected areas. Ecological Modelling. 2015; Vol. 295, 163–175.
7. Barbosa, C. C. F. Álgebra de mapas e suas aplicações em Sensoriamento Remoto e Geoprocessamento. 111 f. Dissertação (Mestrado em Sensoriamento Remoto) – Instituto Nacional de Pesquisas EspaciaisINPE, São José dos Campos, 1997.
8. Padgett J., Tapia C. "Sustainability of Natural Hazard Risk Mitigation: Life Cycle Analysis of Environmental Indicators for Bridge Infrastructure." J. Infrastruct. Syst., 2013; Vol. 19(4), 395-408.
9. Grigio, A. M.; Castro, A. F. De; Souto, M. V. S.; Amaro, V. E.; Vital, H. And Diodato, M. A. Use of remote sensing and geographical information system in the determination of the natural and environmental vulnerability of the Guamaré municipal district – Rio Grande do Norte – northeast of Brazil. Journal of Coastal Research, SI 39, pg – pg. Itajaí, SC – Brazil, ISSN 07490208. 2004.
10. Xavierdasilva, J. et al. Índices de geodiversidade: aplicações de SGI em estudos de biodiversidade. In: Garay, I.; Dias, B. F. S. (Orgs.). Conservação da biodiversidade em ecossistemas tropicais: avanços conceituais e revisão novas metodologias de avaliação e monitoramento . Rio de Janeiro, Vozes, 2001, 299-316.
11. Padgett J., Tapia C. "Sustainability of Natural Hazard Risk Mitigation: Life Cycle Analysis of Environmental Indicators for Bridge Infrastructure." J. Infrastruct. Syst., 2013; 19(4), 395-408.
12. Boori M.S., Ferraro R.R. Global Land Cover classification based on microwave polarization and gradient ratio (MPGR). Geo-informatics for Intelligent Transportation, Springer International Publishing Switzerland.2015; 71: 17-37, Doi:10.1007/978-3-319-11463-7-2
13. Romero A.F., Abessa D.M.S., Fontes R.F.C., Silva H.G. Integrated assessment for establishing an oil environmental vulnerability map: Case study for the Santos Basin region, Brazil. Marine Pollution Bulletin. 2013, 74(1), 156–164.